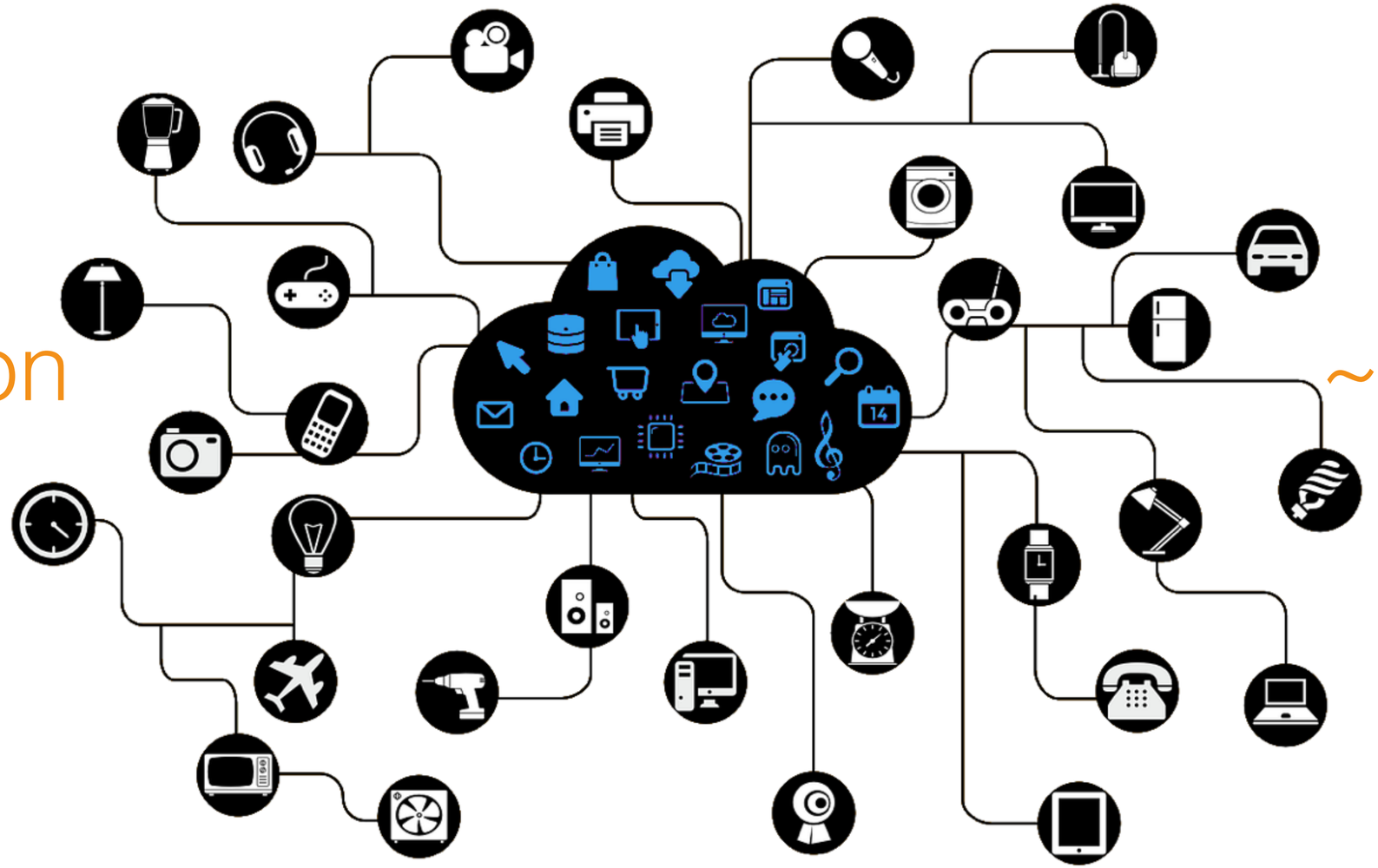
Understanding the Mirai Botnet

Manos Antonakakis[†], Tim April[◆], Michael Bailey[★], Matthew Bernhard[ǂ], Elie Bursztein[✳]
Jaime Cochran[△], Michalis Kallitsis[•], Damian Menscher[✳], Zakir Durumeric[ǂ]
Deepak Kumar[★], Chad Seaman[◆], J. Alex Halderman[ǂ], Luca Invernizzi[✳], Chaz Lever[†]
Zane Ma[★], Joshua Mason[★], Nick Sullivan[△], Kurt Thomas[✳], Yi Zhou[★]

[◆] *Akamai Technologies,* [△] *Cloudflare,* [†] *Georgia Institute of Technology,* [✳] *Google,* [•] *Merit Network*
[★] ***University of Illinois Urbana-Champaign***, [ǂ] *University of Michigan*

Internet of Things

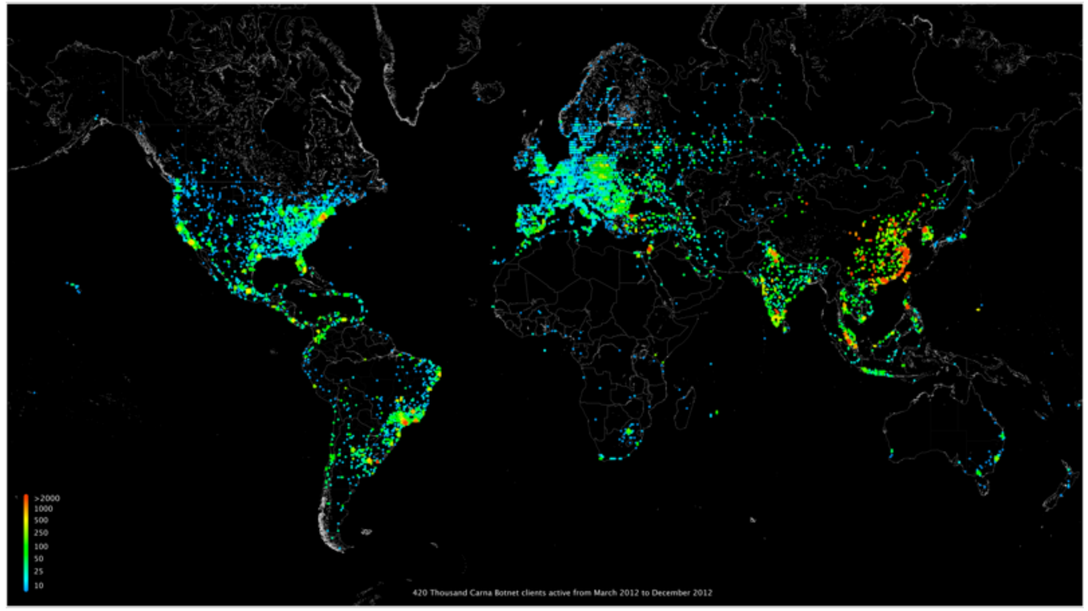
2016
6 - 9 Billion



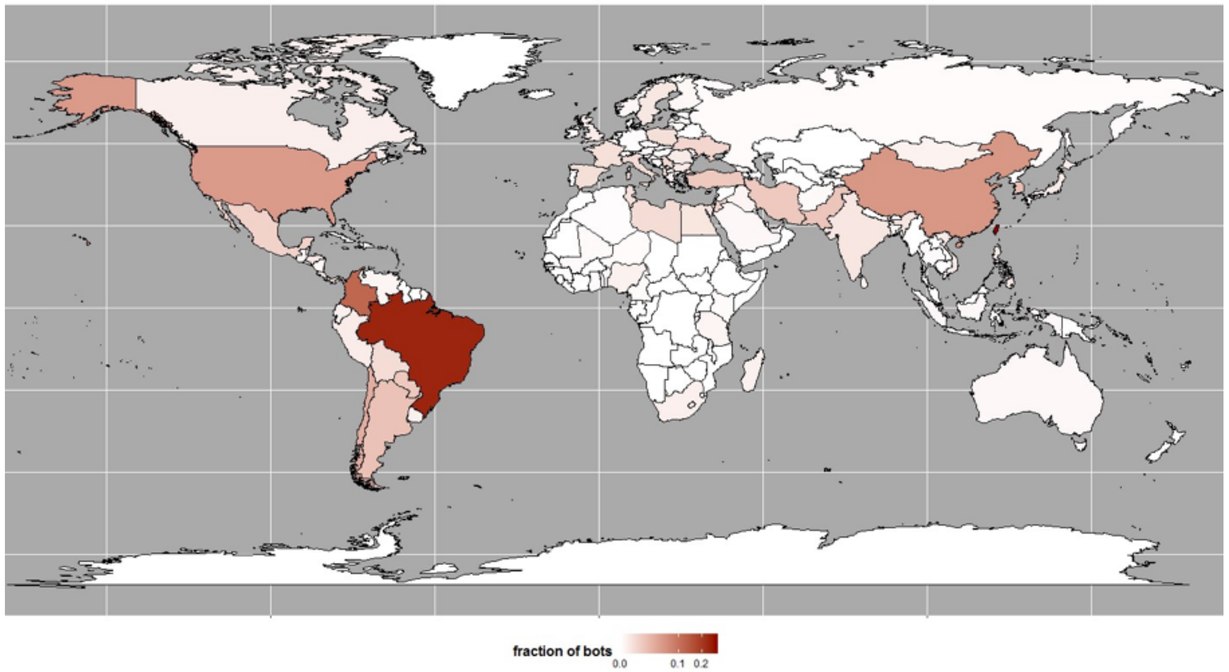
2020
~30 Billion

IoT Botnets

2012 Carna Botnet
420,000 devices



2015 BASHLITE / gafgyt
1,000,000 devices



Mirai

THE WALL STREET JOURNAL.

Cyberattack Knocks Out Access to Websites

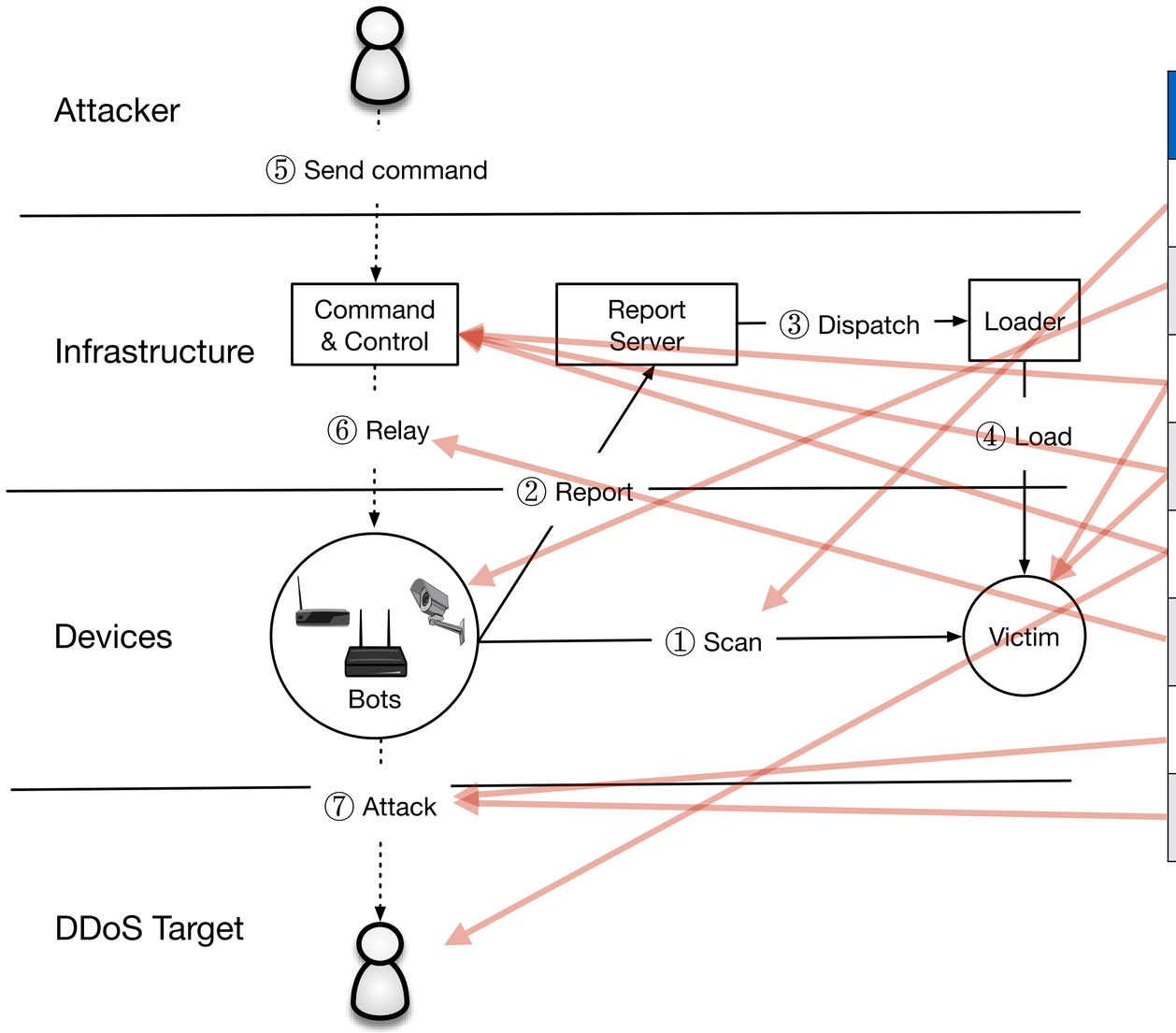
Popular sites such as Twitter, Netflix and PayPal were unreachable for part of the day

21 KrebsOnSecurity Hit With Record DDoS
SEP 16

KrebsonSecurity
In-depth security news and investigation

01 Source Code for IoT Botnet 'Mirai' Released
OCT 16

Measurement



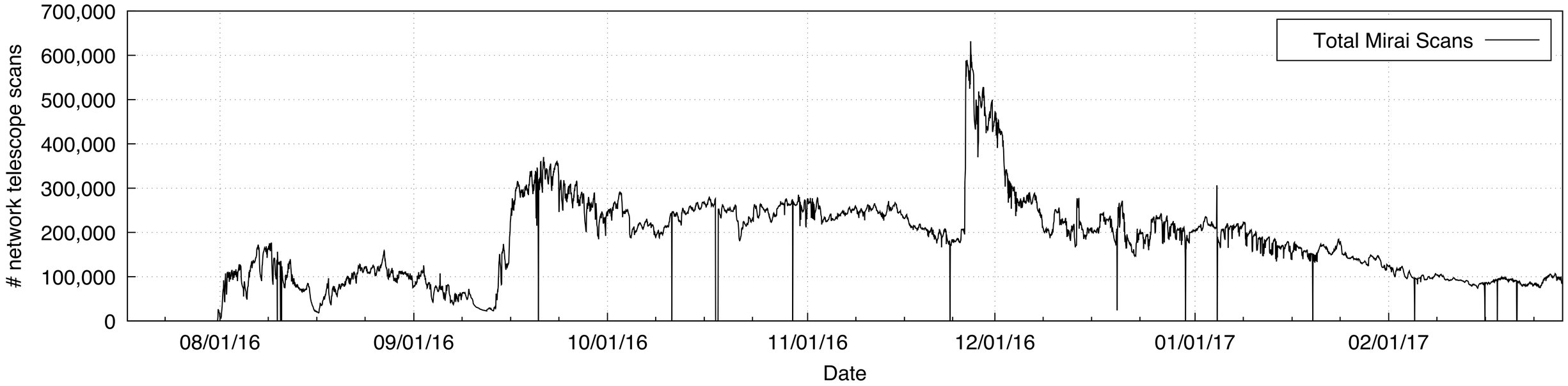
Data Source	Size
Network Telescope	4.7M unused IPs
Active Scanning	136 IPv4 scans
Telnet Honeypots	434 binaries
Malware Repository	594 binaries
Active/Passive DNS	499M daily RRs
C2 Milkers	64K issued attacks
Krebs DDoS Attack	170K attacker IPs
Dyn DDoS Attack	108K attacker IPS

July 2016 - February 2017

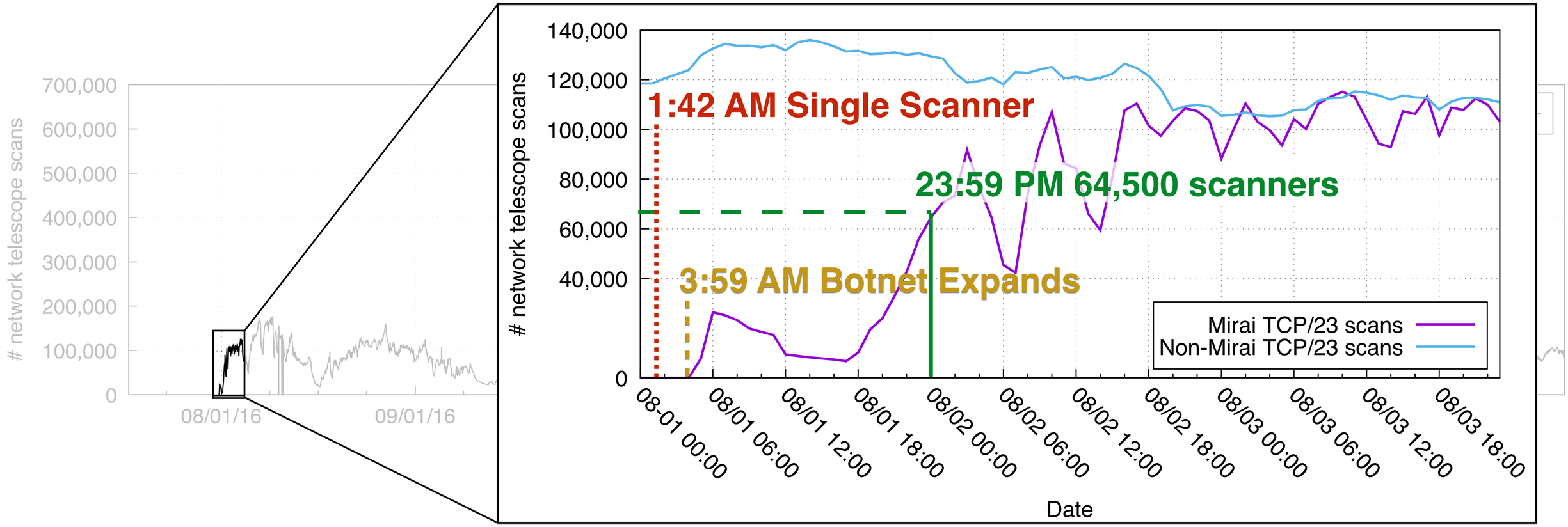
Roadmap

1. **Growth & Composition**
2. Ownership & Evolution
3. Attacks
4. Lessons Learned

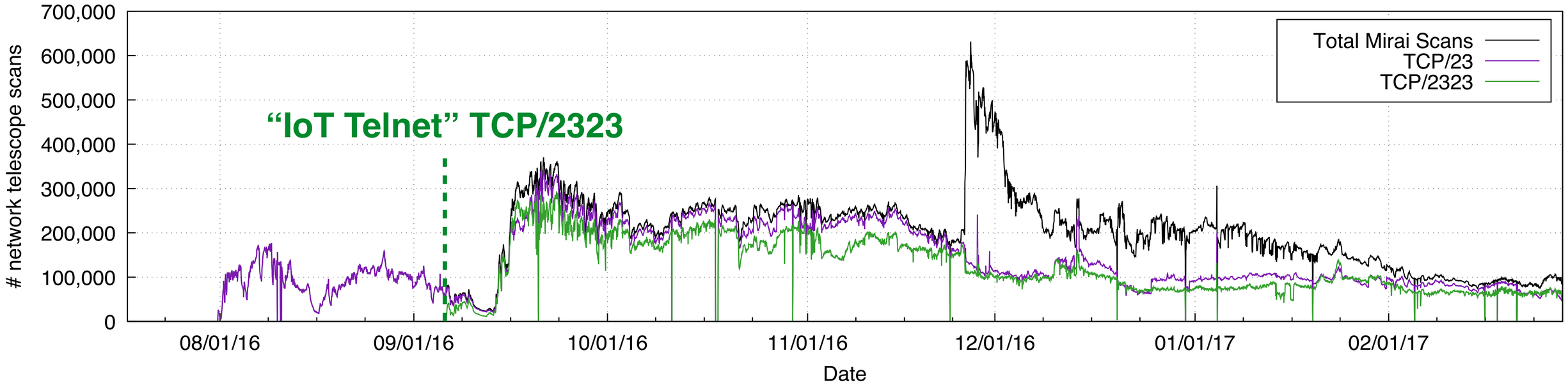
Population


700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
network telescope scans
08/01/16
09/01/16
10/01/16
11/01/16
12/01/16
01/01/17
02/01/17
Date
Total Mirai Scans

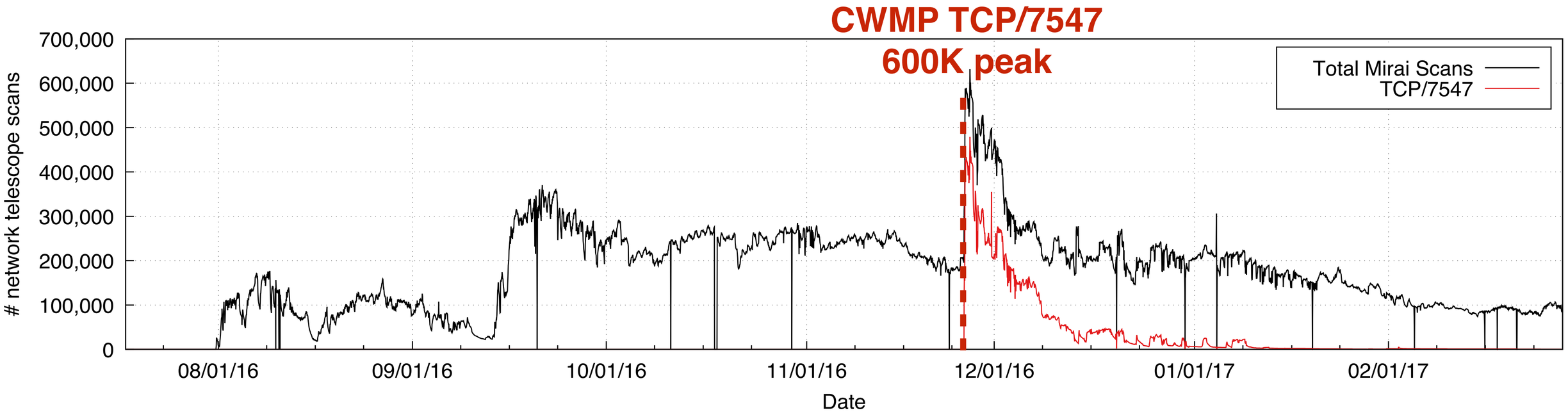
Population


700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
network telescope scans
08/01/16
09/01/16
140,000
120,000
100,000
80,000
60,000
40,000
0
network telescope scans
1:42 AM Single Scanner
23:59 PM 64,500 scanners
3:59 AM Botnet Expands
Mirai TCP/23 scans
Non-Mirai TCP/23 scans
08-01 00:00
08/01 06:00
08/01 12:00
08/01 18:00
08/02 00:00
08/02 06:00
08/02 12:00
08/02 18:00
08/03 00:00
08/03 06:00
08/03 12:00
08/03 18:00
Date

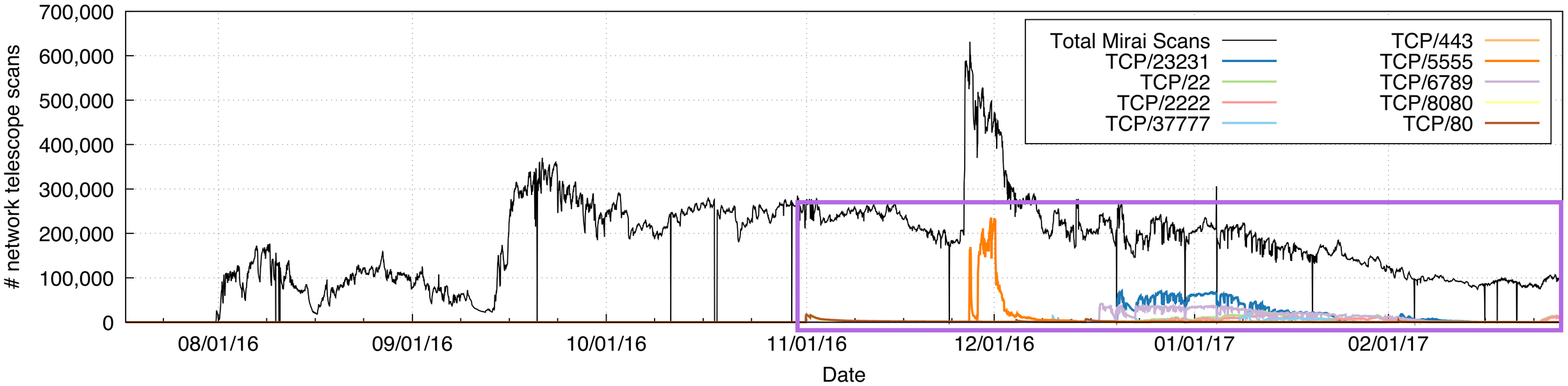
Population


700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
network telescope scans
“IoT Telnet” TCP/2323
Total Mirai Scans
TCP/23
TCP/2323
08/01/16
09/01/16
10/01/16
11/01/16
12/01/16
01/01/17
02/01/17
Date

Population

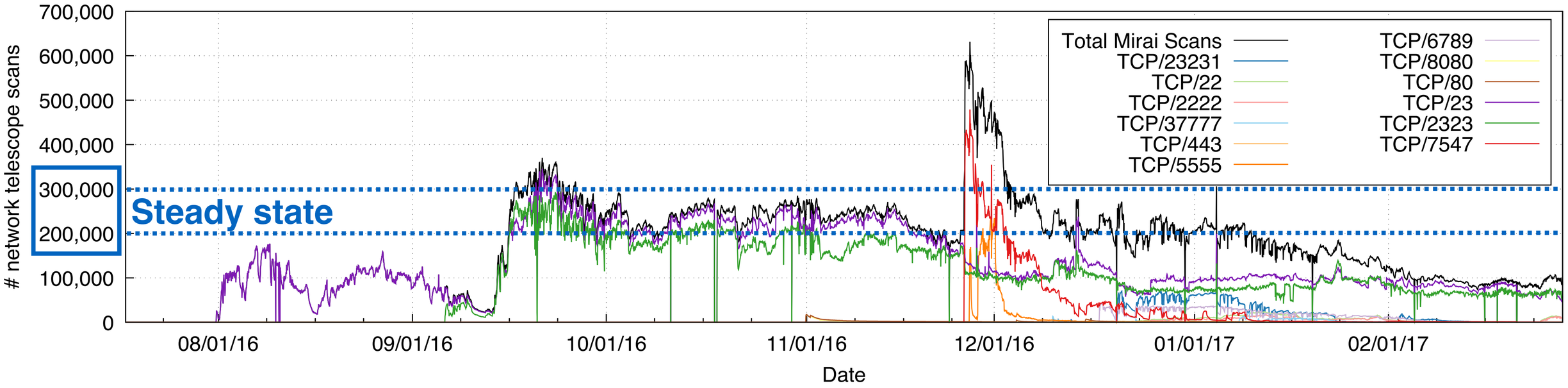

CWMP TCP/7547
600K peak
Total Mirai Scans
TCP/7547
network telescope scans
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
08/01/16
09/01/16
10/01/16
11/01/16
12/01/16
01/01/17
02/01/17
Date

Population



9 Additional Protocols

Population

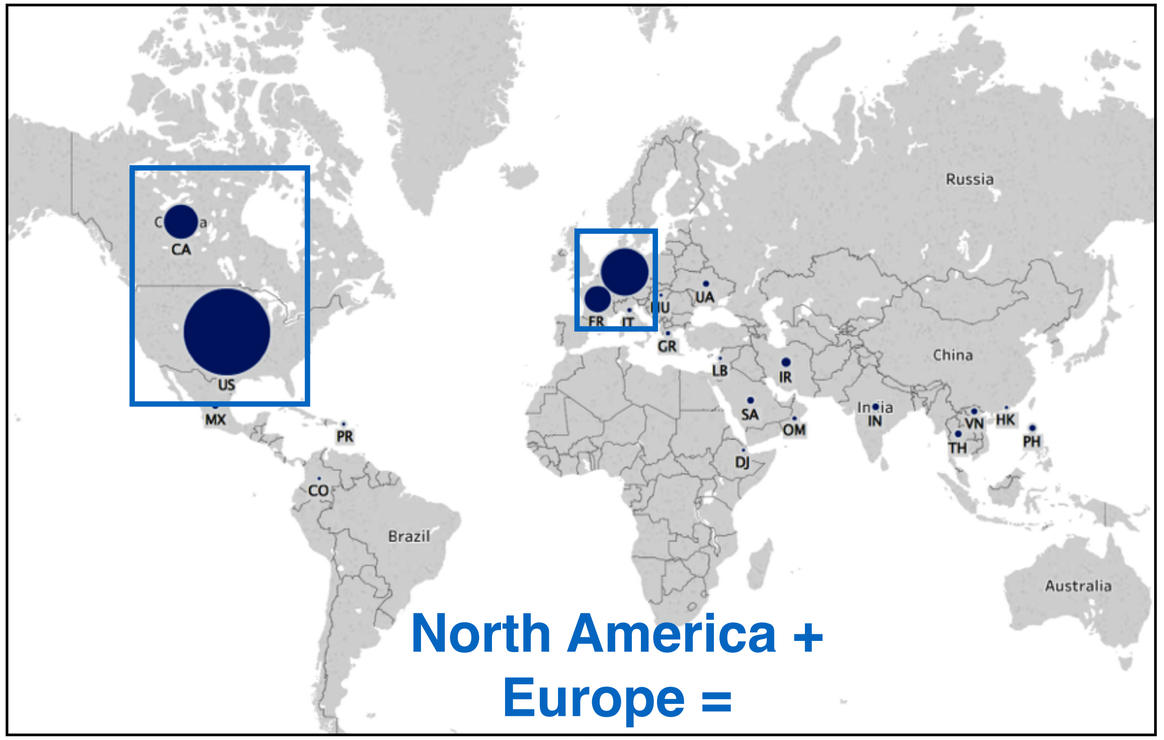

700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
network telescope scans
Steady state
08/01/16
09/01/16
10/01/16
11/01/16
12/01/16
01/01/17
02/01/17
Date
Total Mirai Scans
TCP/23231
TCP/22
TCP/2222
TCP/37777
TCP/443
TCP/5555
TCP/6789
TCP/8080
TCP/80
TCP/23
TCP/2323
TCP/7547

Geography

Mirai

South America + Southeast Asia = 50% of Infections

TDSS/TDL4



North America + Europe = 94% of Infections

Composition

Targeted Default Passwords

Password	Device Type	Password	Device Type	Password	Device Type
123456	ACTi IP Camera	klv1234	HiSilicon IP Camera	1111	Xerox Printer
anko	ANKO Products DVR	jvbzd	HiSilicon IP Camera	Zte521	ZTE Router
pass	Axis IP Camera	admin	IPX-DDK Network Camera	1234	Unknown
888888	Dahua DVR	system	IQinVision Cameras	12345	Unknown
666666	Dahua DVR	meinsm	Mobotix Network Camera	admin1234	Unknown
vizxv	Dahua IP Camera	54321	Packet8 VOIP Phone	default	Unknown
7ujMko0vizxv	Dahua IP Camera	00000000	Panasonic Printer	fucker	Unknown
7ujMko0admin	Dahua IP Camera	realtek	RealTek Routers	guest	Unknown
666666	Dahua IP Camera	1111111	Samsung IP Camera	password	Unknown
dreambox	Dreambox TV Receiver	xmhdipc	Shenzhen Anran Camera	root	Unknown
juantech	Guangzhou Juan Optical	smcadmin	SMC Routers	service	Unknown
xc3511	H.264 Chinese DVR	ikwb	Toshiba Network Camera	support	Unknown
OxhlwSG8	HiSilicon IP Camera	ubnt	Ubiquiti AirOS Router	tech	Unknown
cat1029	HiSilicon IP Camera	supervisor	VideoIQ	user	Unknown
hi3518	HiSilicon IP Camera	<none>	Vivotek IP Camera	zlxx.	Unknown
klv123	HiSilicon IP Camera				

Composition

Infected Devices

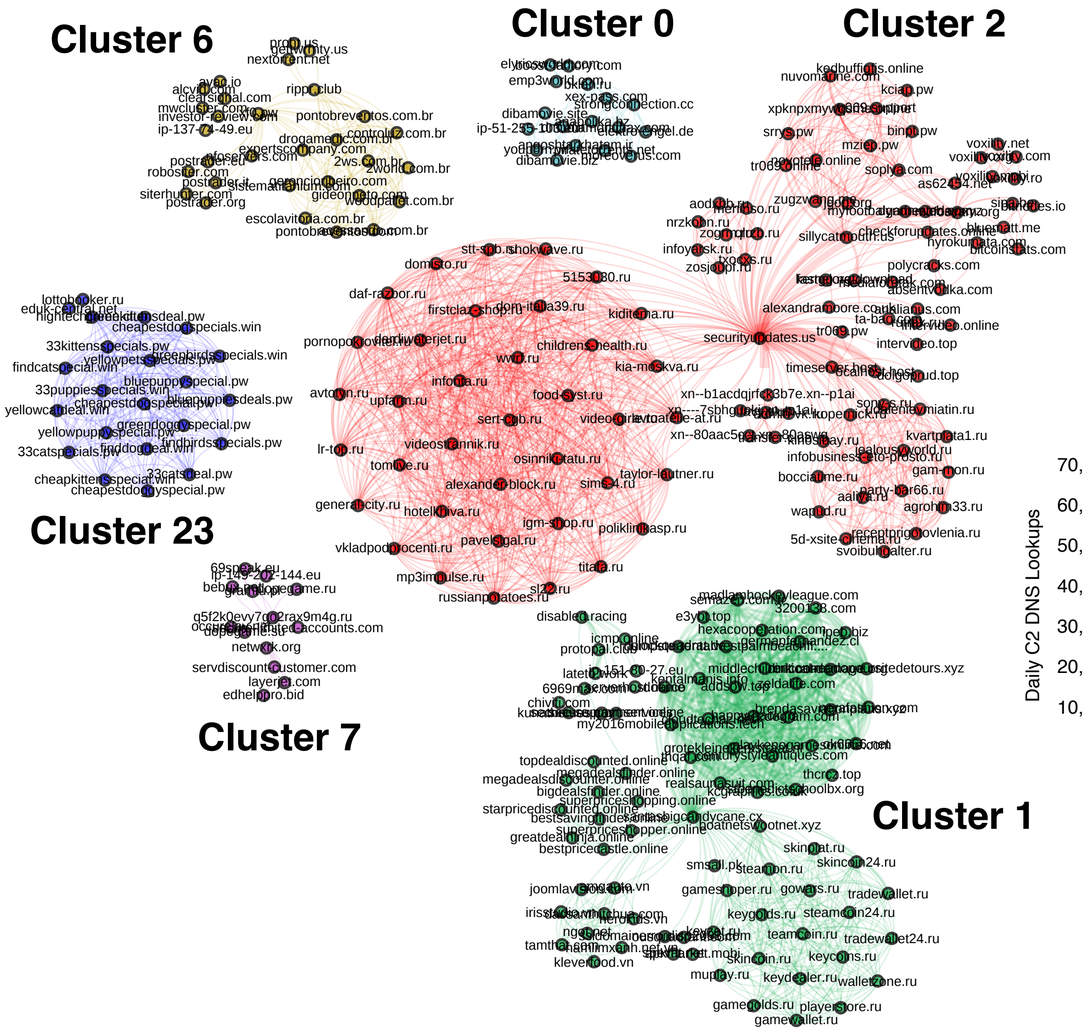
CWMP (28.30%)		Telnet (26.44%)		HTTPS (19.13%)		FTP (17.82%)		SSH (8.31%)	
Router	4.7%	Router	17.4%	Camera/DVR	36.8%	Router	49.5%	Router	4.0%
		Camera/DVR	9.4%	Router	6.3%	Storage	1.0%	Storage	0.2%
				Storage	0.2%	Camera/DVR	0.4%	Firewall	0.2%
				Firewall	0.1%	Media	0.1%	Security	0.1%
Other	0.0%	Other	0.1%	Other	0.2%	Other	0.0%	Other	0.0%
Unknown	95.3%	Unknown	73.1%	Unknown	56.4%	Unknown	49.0%	Unknown	95.6%

CWMP (28.30%)		Telnet (26.44%)		HTTPS (19.13%)		FTP (17.82%)		SSH (8.31%)	
Huawei	3.6%	Dahua	9.1%	Dahua	36.4%	D-Link	37.9%	MikroTik	3.4%
ZTE	1.0%	ZTE	6.7%	MultiTech	26.8%	MikroTik	2.5%		
		Phicomm	1.2%	ZTE	4.3%	ipTIME	1.3%		
				ZyXEL	2.9%				
				Huawei	1.6%				
Other	2.3%	Other	3.3%	Other	7.3%	Other	3.8%	Other	1.8%
Unknown	93.1%	Unknown	79.6%	Unknown	20.6%	Unknown	54.8%	Unknown	94.8%

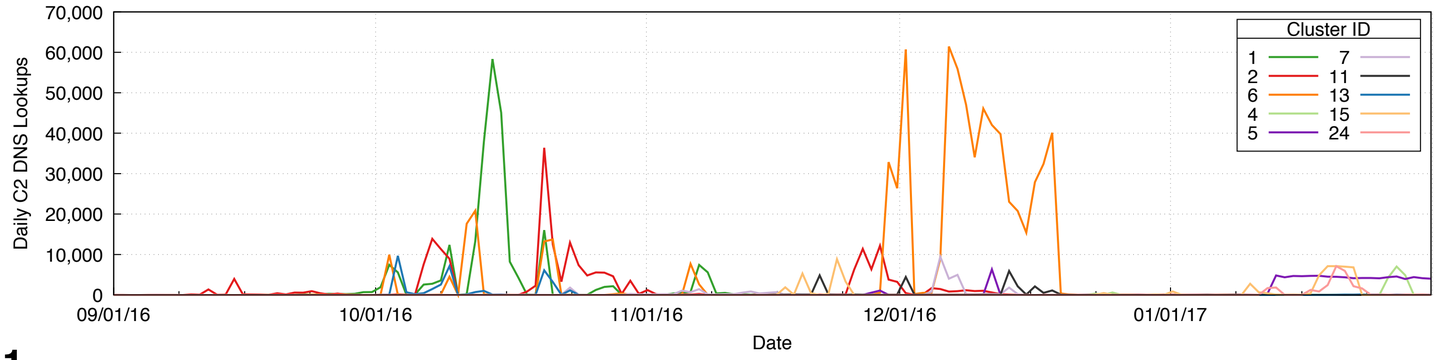
Roadmap

1. Growth & Composition
2. **Ownership & Evolution**
3. Attacks
4. Lessons Learned

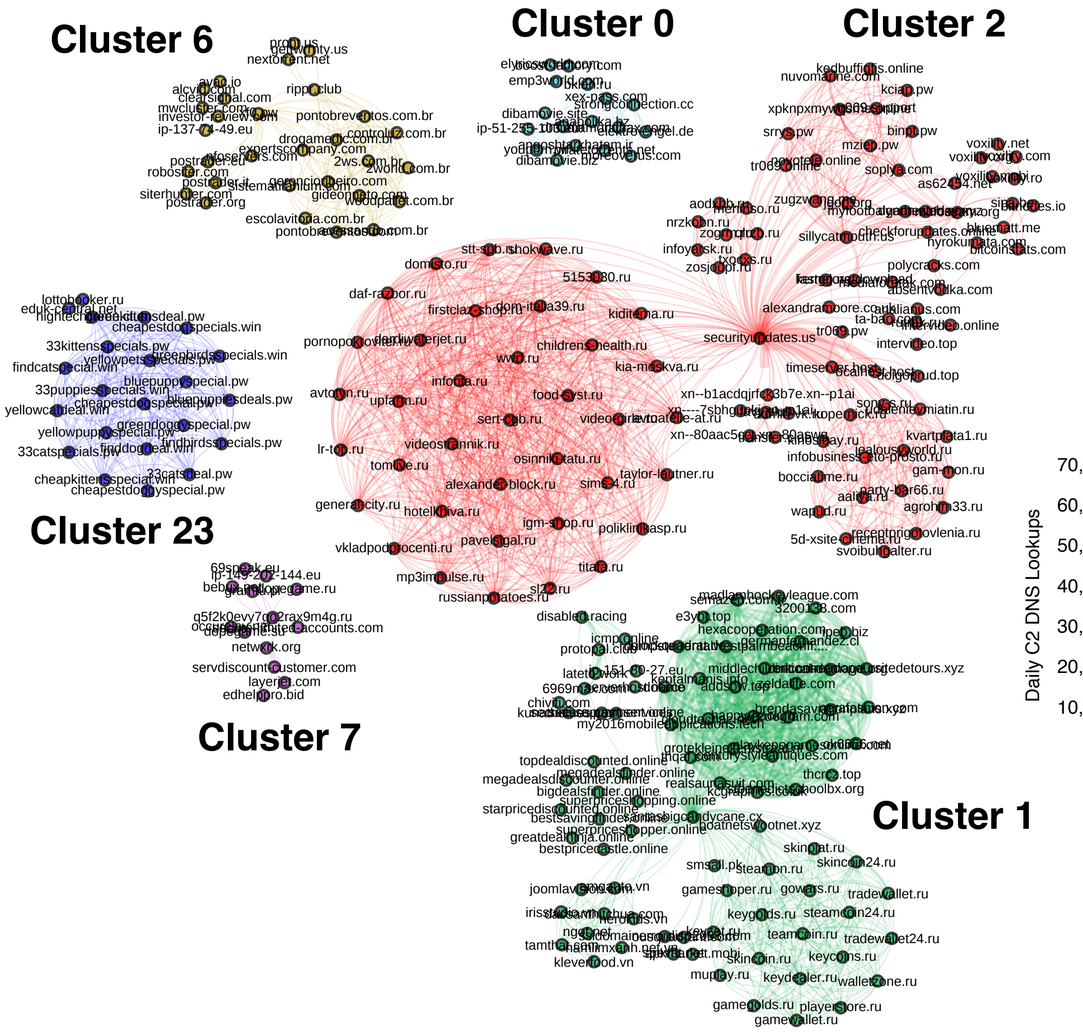
Ownership



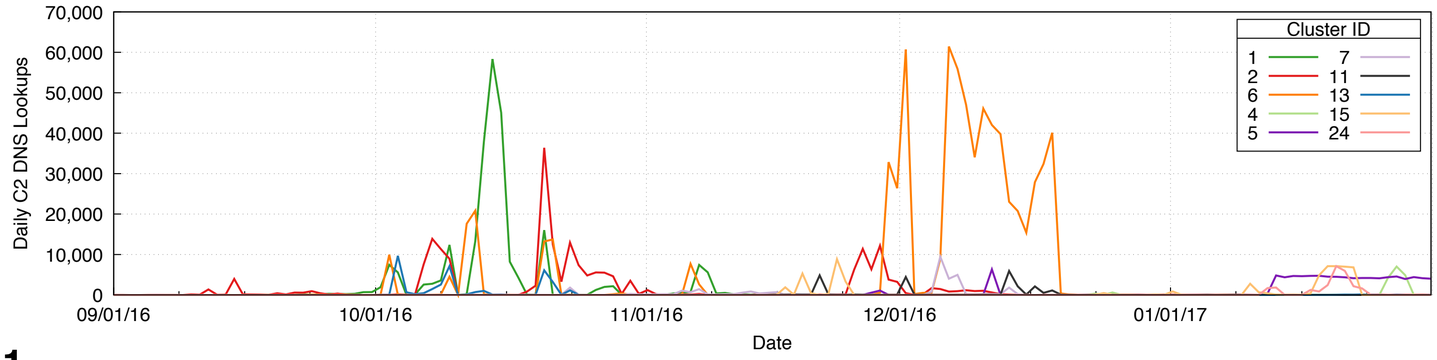
- Extract C2 domains from binaries
- Find coinciding C2s through active and passive DNS data



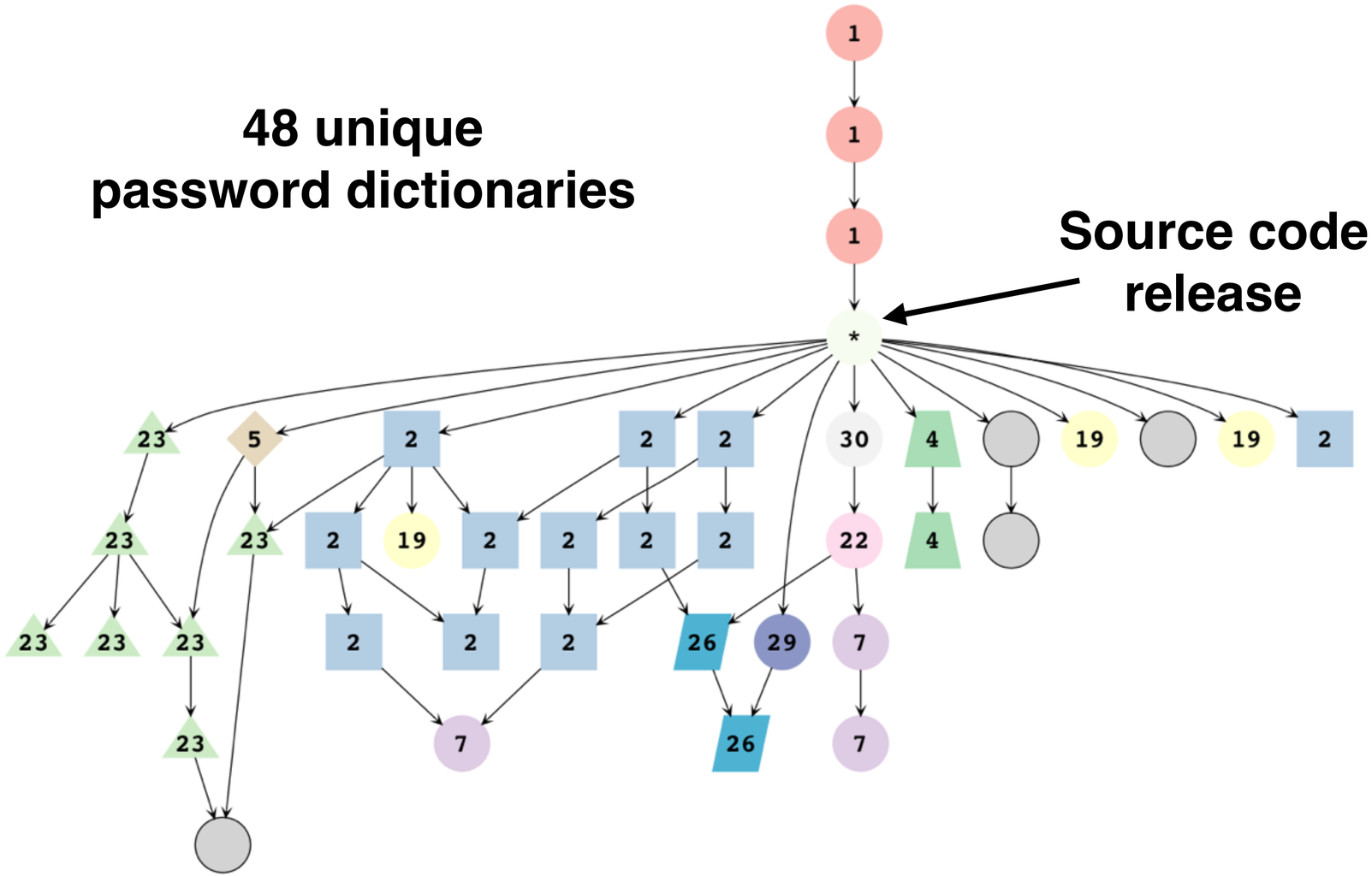
Ownership



Cluster	Notes
1	Original botnet, attacked Krebs, OVH
2	Scans CWMP, adds DGA
6	Attacked Dyn, gaming related sites



Evolution


48 unique
password dictionaries
Source code
release
1
1
1
*
23
5
2
2
2
30
4
19
19
2
23
23
2
19
2
2
2
2
22
4
23
23
23
2
2
2
26
29
7
23
7
26
7

Evolution

DGA

Packing

New protocols

Roadmap

1. Growth & Composition
2. Ownership & Evolution
3. **Attacks**
4. Lessons Learned

Attacks

Attack	Count	%	Class
HTTP	2,736	18.0%	Application
UDP-PLAIN	2,542	16.7%	Volumetric
UDP	2,440	16.1%	Volumetric
ACK	2,173	14.3%	TCP State
SYN	1,935	12.7%	TCP State
GRE-IP	994	6.5%	Application
ACK-STOMP	830	5.5%	TCP State
VSE	809	5.3%	Application
DNS	417	2.7%	Application
GRE-ETH	318	2.1%	Application

- Broad distribution across attack types, compared to Arbor report 65% volumetric, 18% TCP state, 18% app
- VSE = Valve Source Engine, popular game server
- Little reflection/amplification: 2.8% reflection attacks, compared to 74% for booters

Attacks

Target	Attacks	Cluster	Notes
Lonestar Cell	616	2	Liberian telecom targeted by 102 reflection attacks.
Sky Network	318	15, 26, 6	Brazilian Minecraft servers hosted in Psychz Networks data centers.
1.1.1.1	236	1,6,7,11,15,27,28,30	Test endpoint. Subject to all attack types.
104.85.165.1	192	1,2,6,8,11,15,21,23,26,27,28,30	Unknown router in Akamai's AS.
feseli.com	157	7	Russian cooking blog.
minomortaruolo.it	157	7	Italian politician site.
Voxility hosted C2	106	1,2,6,7,15,26,27,28,30	C2 domain from DNS expansion. Exists in cluster 2 seen in Table 8.
Tuidang websites	100	—	HTTP attacks on two Chinese political dissidence sites.
execrypt.com	96	—	Binary obfuscation service.
auktionshilfe.info	85	2,13	Russian auction site.
houtai.longqikeji.com	85	25	SYN attacks on a former game commerce site.
Runescape	73	—	World 26 of a popular online game.
184.84.240.54	72	1,10,11,15,27,28,30	Unknown target hosted at Akamai.
antiddos.solutions	71	—	AntiDDoS service offered at `react.su`.

Dyn Attack

The New York Times

"It is possible, investigators say, that the attack on Dyn was conducted by a criminal group that wanted to extort the company. Or it could have been done by "hacktivists." Or a foreign power that wanted to remind the United States of its vulnerability."

Dyn Attack

The New York Times

"It is possible, investigators say, that the attack on Dyn was conducted by a criminal group that wanted to extort the company. Or it could have been done by "hacktivists." Or a foreign power that wanted to remind the United States of its vulnerability."

Targeted IP	rDNS	Passive DNS
208.78.70.5	ns1.p05.dynect.net	**ns00.playstation.net**
204.13.250.5	ns2.p05.dynect.net	**ns01.playstation.net**
208.78.71.5	ns3.p05.dynect.net	**ns02.playstation.net**
204.13.251.5	ns4.p05.dynect.net	**ns03.playstation.net**
198.107.156.219	service.playstation.net	**ns05.playstation.net**
216.115.91.57	service.playstation.net	**ns06.playstation.net**

- Top targets are linked to Sony PlayStation
- Attacks on Dyn interspersed among attacks on other game services

Roadmap

1. Growth & Composition
2. Ownership & Evolution
3. Attacks
4. **Lessons Learned**

New Dog, Old Tricks

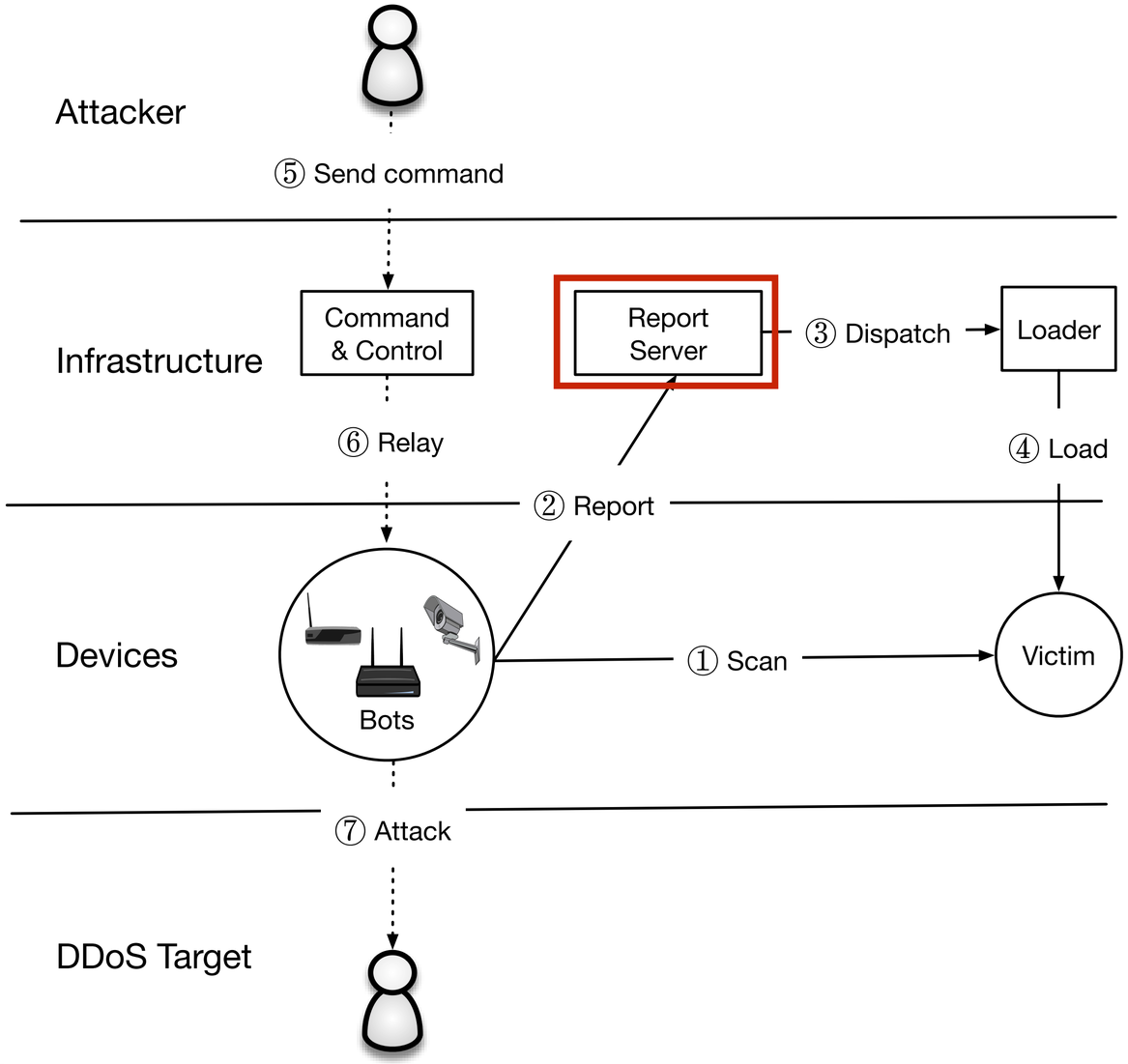
1. Security Hardening
2. Automatic Updates
3. Device Attribution
4. Defragmentation
5. End-of-life

REAL Lessons Learned

1. **19 authors?!**

REAL Lessons Learned

1. 19 authors?!
2. **Report server visibility**



REAL Lessons Learned

1. 19 authors?!
2. Report server visibility
3. **Scandemonium**

Stateless, Internet-wide scanning is increasing

Benevolent and malicious

REAL Lessons Learned

1. 19 authors?!
2. Report server visibility
3. Scandemonium
4. **Device identification is hard**

Telnet banner

```
(none) login:
```

Only ~20% of devices identified to any extent

REAL Lessons Learned

1. 19 authors?!
2. Report server visibility
3. Scandemonium
4. Device identification is hard
5. **Especially for good guys**

Cannot use the same techniques as bad guys

Internet of Things (IoT) Cybersecurity Improvement Act of 2017!

https://www.congress.gov/bill/115th-congress/senate-bill/1691/text

Understanding the Mirai Botnet

1. Growth & Composition
2. Ownership & Evolution
3. Attacks
4. Lessons Learned
5. **Questions?** **zanema2@illinois.edu**

Future Research Directions

1. Automatic detection of new protocols - universal honeypot
2. Improved IoT device identification / fingerprinting
3. IoT device identification system